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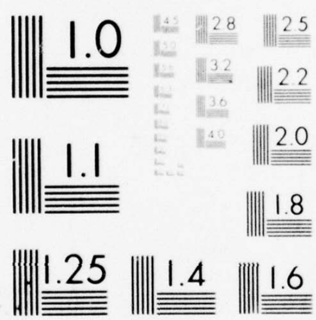

MICROCOPY RESOLUTION TEST CHART
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- Electron Beam Recorder
- Optical Recorders
- Laser Devices
- Incandescent Devices
- Light Emitting Diode (LED) Devices
- Cathode Ray Tube (CRT) Devices
- Ink on Paper Devices

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report determined the types of hard copy devices available, the relative advantages and disadvantages, and cost for the various systems. Manufacturers were identified that produced hard copy display systems. The objective of the report was to review as many types of instruments as could be located. Results of the survey found that there is little that is new in the field. The basic system types included flying spot scanning, a few laser devices, rotating drum with incoherent sources, and several flat bed systems based on microdensitometer techniques.

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SURVEY OF DISPLAY DEVICES
(HARD COPY)

by

C. L. Patterson

June 1976

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Acknowledgement

The survey of digital image hard copy systems reported herein was performed at the request of the Engineering Topographic Laboratories. The personnel having cognizance over the effort from the Engineering Topographic Laboratories include:

Mr. W. Boge
Mr. L. Gambino
Dr. B. Schrock

The writer was assisted in this survey by Ms. M. M. Irvin.

Forward

The survey reported herein is one of a series prepared for the Engineering Topographic Laboratories as an aid in the development of a major digital image processing facility. The other volumes in the series include:

1. "ETL Computer Facility Optimization Study", by D. J. Theis, June 1976.
2. "Survey of Digital Image Display Systems (Soft Copy)", by C. L. Patterson, June 1976.
3. "Survey of Digital Image Scanning Systems", by M. M. Irvin, June 1976.
4. "Software Studies", by G. Buechler, June 1976.

INTRODUCTION

Historically the storage and display medium for images has been film or paper. There is little reason to believe that the natural preference will change, simply due to the fact that the image has been collected or processed by digital techniques. Many reasons exist for the natural preference, not the least of which is the reluctance to change on the part of the interpreter of the image data. There are, however, substantial reasons why the preference should not change. Archival storage is considerably simplified by film as a mechanism for storage of image data, in that there are no higher density storage media. If several interpreters in distant locations are to read the same image, then film is the ideal mechanism for the transport of the image if it is desired that each interpreter view exactly the same image. With the soft copy systems it is considerably more difficult to assure that the same properties are displayed due to the variable characteristics of the display system (monitor). If film is used, it is relatively straightforward to assure the quality of duplicate positives or negatives. Perhaps the single most important reason, however, for reliance on film is the size of the image which can be written. Most display systems, using soft copy devices, are limited to 2048 x 2048 pixels (e.g., the Dicomed D-36) and many are limited to a 512 x 512 pixel display. Film on the other hand can easily be written at 4096 x 4096 pixels or greater. Whatever the reason, film is, and will remain, an important element in the digital image processing system.

The objective of the survey was to determine the types of hard copy devices available, the relative advantages and disadvantages, and cost for the various systems. As in any survey, there exists no mechanism to assure that all available devices are covered. This survey is no different. It is believed, however, that most current technology is represented in the results.

SURVEY TECHNIQUE

The hard copy display system survey was based primarily on the review of manufacturer literature. Some of the review, however, was based on discussions with users of the various systems available. No in-plant visits were made since there was little to be gained from viewing the instruments. A literature search was made to identify manufacturers which might have the capability to manufacture hard copy display systems. Each identified manufacturer was contacted by telephone to request detailed literature such as specifications to be mailed to the writer for review. It was noted that many of the potential suppliers of hard copy devices were heavily involved with the manufacture of scanning micro-densitometers and many of the instruments were housed in the same piece of equipment. As a result, there will be a great deal of commonality between reports on the surveys of the two types of instruments.

Objectives of the hard copy display systems survey was to review as many types of instruments as could be located. The key word here is types. In many instances various manufacturers are offering almost identical instruments, and it seemed unnecessary to include an exhaustive survey of all of the specific systems. The survey was based on devices which are "off the shelf". Single instruments which were built for singular applications were deleted. It should be noted that many of the singular applications were associated with a company's desire to build for their own in-house use.

Prior to beginning the survey on hard copy devices, an attempt was made to organize the types of systems expected. The purpose of the classification or organization was to aid the writer in assuring that the various types would be represented in terms of real systems. The types or classifications were based on the writer's experience with the hard copy systems. No attempt was made to utilize the classification in the documentation. Later in this report fact sheets on those equipments investigated will be found.

At the coarsest level, hard copy systems may be classified in terms of the energy source used to write the image. The systems covered in the survey tended to confirm the classification technique. In particular, the energy sources include: electron beam recording, optical recording, and ink on paper

techniques. Of these classifications, the optical recording techniques represents the largest class and may be further broken down into a number of subclasses. Only one electron beam recorder and one ink on paper recorder were found to represent their individual classes. The outline shown below indicates the major and sub classes identified in the survey.

I. Electron Beam Recorder (EBR)

II. Optical Recorders

   A. Laser Devices

   B. Incandescent Devices

   C. Light Emitting Diode (LED) devices

   D. Cathode Ray Tube (CRT) devices

III. Ink on Paper devices

Optical recorders may be alternatively grouped into the class of mechanical technique required to cover the film sheet being recorded. The mechanical techniques are much the same required in the microdensitometer systems reviewed in a separate report. The basic mechanical systems include: flatbed devices, wherein the film to be written lies on a flat surface and the light beam is caused to move over the film sheet or the film sheet is moved in a plane under the light source; a rotating drum device wherein the film is mounted on a drum which in turn is rotated around the light source such that a line is written during a revolution of the drum or some fraction of the revolution; a rotating flat face which reflects the light beam on the film sheet such as to write out a line of data per revolution of the flat mirror surface.

The CRT systems are very much like the flying spot scanner in that the illuminated point under the electron beam traces out a predetermined pattern, such as a raster, with a modulated beam.

A still further technique for classification of scanner type is the beam versus the matrix address technique. No matrix address schemes were uncovered in the course of the review of the state-of-the-art made but the approach would have much in its favor if one were available in that the random address capability could be used in a number of potentially interesting applications. Many of the devices surveyed do have a capability which is close to the pure random address, in that a vector capability is available. The option, if available, may prove very useful in a general sense for both curve plotting as well as image generation.

Results of the survey on hard copy devices are presented as a series of short descriptions. The reason for this particular approach as opposed to the "matrix" technique is to allow evaluation of each system independently. If the data were arrayed in the usual matrix form, then it would be impossible to avoid direct comparison. It was believed that, since each manufacturer offers a large number of options, a direct matrix comparison would inevitably be unfair as it would be a difficult if not impossible task to indicate all of the options available on the comparison matrix.

DISPLAY SYSTEM SPECIFICATIONS

No specific specifications were available to describe the requirements that ETL might have regarding hard copy display systems. It does seem appropriate to make some comment regarding system level specification. It is assumed that the ETL requirements must address both the research and development activities as well as some requirement for high volume production of hard copy image generation. The two requirements are not necessarily in conflict with one another, but if one were to place high emphasis on the research and development, then the high volume requirements may not be met.

Criteria which should be applied to a hard copy film writer include many elements which relate to the specific application of the device. There are, however, many which are rather independent of the application. It is the application independent requirements with which this section is concerned. Some of the parameters which are general in nature are outlined in the following:

1. geometric precision
2. radiometric precision
3. speed of write (throughput time)
4. color capability
5. aperture selection
6. overlap
7. operability, maintainability, and reliability

A set of brief comments on each of these areas is included in the following paragraphs.

Geometric Precision

There are several parts to the geometric precision problem. The first of these is the orthogonality of axes. It is normally assumed that the film writer is to be used in a broad class of operations all of which are dominated by the distortion requirements. Deviations from orthogonality cause a distortion in the image displayed.

In the problem of geometric precision, the point-to-point accuracy must be considered. The accuracy of placing two pixels side by side is of particular importance in many applications and in general should be of the order of 0.1 of the pixel size (effective aperture size on the film). The accuracy must be considered in both axes simultaneously such that the rms of both axes is less than 0.14 pixels. In order to control the build up of error in a large playback, the maximum error between any two points across the format (maximum) must also be specified. In general, this maximum displacement must be less than the smallest aperture to be used in the playback of an image.

In many applications, it is important to control the error in rescanning an image. As an example, a sequential scan for color is heavily dependent in a quality sense on the accuracy in restarting the playback at the correct point. Any backlash in the drive system that is not measured or compensated for will result in intolerable errors. In general, the error should be less than 0.1 pixels (using the smallest aperture) in each axis.

Another parameter which relates to the geometric precision is the line start jitter. The error is similar to the point-to-point accuracy noted in a previous paragraph. In many instances, however, the image is more sensitive to the line start error than the point-to-point error noted. The line start jitter is the error made in starting each new line of image data. If the error is visible to the interpreter, the interpreter will tend to distrust the image generated. The 0.1 pixel per axis criterion is generally acceptable in the sense of the point-to-point accuracy noted above.

Radiometric Precision

Radiometric precision is a generally ignored parameter in specification of film writers. In general, the eye is relatively insensitive to minor errors in radiometry (unless it is desired to make a measurement on film - if this is desired, the measurements should be made directly with the digital data base prior to the purging of the digital file). The problem that does cause visible degradation is the number of bits displayed. If too few levels are displayed, then the image may take on a mottled effect due to "bit contouring". A minimum of 6 bits is recommended to reduce the effect

(8 bits would be preferred). It should also be noted that the obvious problem of non-monotone radiometric transfer is particularly bad. As to a specification, the radiometric error should not exceed plus or minus 1/2 of the least significant bit of the image data (that is the error should not exceed approximately 0.01 of the maximum for a 6 bit system).

Two other areas which are closely related to the radiometric precision error and which are frequently overlooked are those associated with the minimum intensity desired and the maximum rate of change of the signal level. Many of the devices used for the light source cannot be extinguished completely without severe repercussions in hardware complexities (this occurs on certain laser systems). If a laser device is considered with or without optical modulators, then a higher allowed minimum intensity will simplify the design. Obviously the simpler designs have a very favorable impact on costs. The maximum rate of change of signal (radiometric) is one of the subtle problems that is almost never specified. If the signal changes from full on to full off in one pixel distance, the digital to analog converters and following electronics are "strained". The bandwidth of the system is defined by the rate of change of the signal rather than the pulse width. Use of pulse width to define bandwidth is an approximation commonly used. The effect may generate radiometric error or even oscillation in the radiometric output if the design does not allow for the rate of change phenomena. The usual "fix" is to slow the instrument down thus impacting the throughput time for a playback.

Writing Speed (Throughput Time)

Writing speed has been one of the most thoroughly specified parameters in hard copy display systems. The writing speed, of course, determines to a very large extent the throughput time required to display an image. Almost all major developments in film writers during the past several years have been in response to ever increasing demands to decrease throughput time. Laser devices are the industry's answer to the limiting speed. The laser systems are required for the very fast throughput time in order to get the power on the film to a sufficient level to produce the desired exposure. Such systems are, of course, much more expensive. In many instances the devices have compromised geometric precision and

radiometric fidelity in order to reduce cost to an acceptable level. Some of the problems which have resulted from the very fast systems include: high fog level due to incomplete extinction of the optical beam, difficulties with reciprocity failure in the film (which is rarely accounted for by the manufacturers); and excessive costs for the system. In general, the specification should attempt to call for the very maximum throughput time to reduce or eliminate the need for the laser systems.

Color Requirements

Color requirements have not been clearly established in the digital image processing field, especially in the hard copy display systems. There have been limited studies with soft copy devices which tend to indicate that color will be of value in the generalized interpretation problem. Color as discussed herein means all applications such as: true color (i. e., obtained from photography); false color (multiple image overlay using color for the different images); and pseudocolor (such as replacing gray scale values with color on an "arbitrary basis"). It is believed that color should be seriously considered for hard copy applications in any digital image processing facility. There are several parameters which should be specified when considering a color recorder which differ from those of a standard black and white system. The additional parameters include: color plane registration accuracy; spectral purity of the individual color sources; and the span of the color space such as the CIE color volume. Registration of the color images should be of the order of 0. 1 pixels per axis (consistent with the geometric properties of the black and white recorders previously discussed). The color parameters are not so easily established due to the general lack of knowledge of color vision properties of the observers. Additional information must be made available from the psychovisual community before any specific parameters can be established.

Aperture Requirements

Specification of a set of apertures for playback systems is one of the most critical parameters available to system designer and user. The aperture acts as a final filter in the image processing chain and as such can

be used to enhance or degrade the final product. A great deal of care should be exercised in selecting the apertures to be used in any playback system. (The problem is equally severe in the soft copy devices but is rarely recognized as such.) There are many aperture forms available including various shapes, sizes, and shadings. The shaded apertures are those in which the transmissive portion is modified to produce a variety of responses. The aperture shapes should include the square, circular, and rectangular at the minimum. The recommended shapes of square, circular, and rectangular are, based on the writer's experience, the most useful. In some instances, other shapes such as elliptical and triangular could be of some value but are at a much lower priority than the basic shapes. It should also be noted that the latter shapes are rarely encountered but could be of value in cases where the resolution of the original photography of digital base is characterized by non-symmetric spot shapes. As to sizes, the minimum size should be consistent with the intended application. At this time it seems unlikely that sizes less than 5 micrometers would be of use due to limitations in film and final product dimensions. The maximum size should not be much greater than 1.0 mm for most practical applications (that is, a 512 x 512 image would be of the order of 51.2 cm on a side which is more than enough). The range in aperture size should be broken up into 10 or 15 segments with 10 being a convenient size, although the number of segments is not a particularly severe restriction of the system, since the primary impact is in the film size to be handled. If one were to hold to standard film sizes, such as 35 mm, 70 mm, 100 x 125 mm, etc., then only 6 or so apertures are required. The limitation depends upon the sizes of the images to be displayed as well; it is assumed that the image size will be of the order of 512 x 512, 1024 x 1024, 2048 x 2048, 3072 x 3072 picture elements. Any special configurations must also be specified. The aperture shading is a particular problem as it is rarely considered in the general playback system. In many cases it is desirable to limit the high frequency response of a playback system for noise control or for enhancement. The effect is easily obtained if the clear aperture is shaded by reducing the optical transmission as a function of position within the nominal aperture. Several shadings have been proposed in recent studies including: triangular Gaussian, sinc (sin x/x), sinc squared, hanning and Hamming. Each of

the windows noted has a particular reason for being, which will not be discussed in the context of this report. It is sufficient to note that each is symmetric and expandable in the form of a cosine power series; in general, any shaded window function should have the symmetric form for control of undesirable side lobe phenomena. An excellent reference on the window functions is "Measurement of Power Spectra", by Blackman and Tukey published by Dover. The shaded windows are difficult to manufacture mechanically in terms of "cutting" metal, however, they are relatively easy to build photographically. The photographic technique will usually allow for easy manufacture of special forms as the need arises. The ability to implement shaded apertures should be seriously considered. It should be noted as a final comment, many have considered the use of overlap of spot to accomplish a form of approximate shading with binary (off-on) windows. The approach is a worth candidate for further study. However, it is noted that such an approach would have the effect of significantly increasing the amount of data to be handled and would result in additional computing required to produce the overlapped image matrix.

Overlap Requirements

A very closely related problem to the aperture effects is that of overlap introduced in the preceding paragraph. Overlap is defined herein as the amount of common pixel energy allowed by the system and will be given herein as the percent of common space occupied by two pixels (that is, 100% overlap will correspond to two pixels occupying the same film space). The specified amount of overlap will have to be consistent with the total or overall system accuracy requirements and will have to be given with respect to the aperture size. If the overall accuracy required is 0.1 pixel per axis, and the minimum aperture is 5 micrometers, then overlap capability is in integer multiples of 10% (i.e., 100%, 90%, 80%, etc., to 0%). Spatially the overlap varies in multiples of 0.5 micrometers. The spatial intervals of 0.5 micrometers are too small to be practical (anything less 1.0 micrometer should be viewed with suspicion). In the

manner of a compromise, the specification should allow step size of 1.0 micrometers and the user can then set whatever overlap is desired. The required step size and overlap problem is less than satisfactory for the minimum aperture size. Some specification should be made regardless of the problems.

Operability, Maintainability, and Reliability

Operability, maintainability, and reliability specification on the playback system are, if anything, more critical than those for other equipment in the digital image processing facility. Many of the potential systems concepts are extremely complex in obtaining a playback system. It is also important that the equipment be relatively simple to operate and to maintain. Specifications should be prepared to indicate, at the minimum, the operational constraints under which the equipment must function. The scope of this report does not include a detailed review of the operational constraints expected at ETL. It is in the nature of a caution that the operability, maintainability, and reliability are noted herein. Other users of hard copy systems have reported considerable problems with respect to these areas. A detailed review of the experience of other users is strongly recommended to determine the appropriate requirements on these areas. A series of reports was sent to Mr. L. Gambino summarizing some of these problems with respect to the Perkin-Elmer (Boller & Chivens Division) PDS model 1010A microdensitometer. The specific device problems are summarized in the following documents:

1. "Preliminary Recommendation for Film Printing with the Boller & Chivens PDS Model 1010A Microdensitometer", R. P. Kruger for The Aerospace Corporation, June 5, 1975

2. "A Partial Evaluation of a PDS Microdensitometer", J. Geary et al, Optical Sciences Center, University of Arizona, Tucson, Arizona, August, 1975

3. "Selection of Device Parameters for Film Printing with the Boller & Chivens PDS Model 1010A Microdensitometer, ESL, Inc. Report Number 8649, 30 April 1975

SURVEY RESULTS

Results of the hard copy system survey are summarized in the following section. Many details were omitted in the interest of readability of the report. The objective was not to produce large quantities of documentation but were to produce a review of the current state-of-the-art in hard copy playback devices. Detail data sheets as made available by the various manufacturers can be provided if desired.

A list of manufacturers covered in the course of the hard copy display survey is given in the attached appendix along with addresses and phone numbers as available.

The survey results are presented in the alphabetical order of the manufacturers. No attempt was made to organize the devices in accordance with the technique used. The technique will be described as appropriate under the individual device/manufacturer.

In some instances well known manufacturers have dropped product lines relating to the hard copy systems. In some of the cases, the product line has been taken up by new companies. The new manufacturer will be given as the manufacturer but the former will be identified as appropriate.

As indicated earlier, the results are given in the form of descriptive paragraphs to allow independent evaluation of the basic instruments and available options. Each organization is covered in isolated sections.

California Computer Products, Inc.

California Computer Products (Calcomp), Inc. produces a film writer system which is nominally directed to the computer graphics industry. However, several organizations have successfully used the devices as an image printing device. The primary problem noted in the earlier Calcomp devices (and also noted in the current version) is the limited gray scale available (typically 32 levels). Two such devices are manufactured by Calcomp (to the writer's knowledge) namely, the Model 835 and the 1675 Graphic Com System. The Model 835 is an older version and will not be described in detail herein.

The 835 plotter system will plot a matrix of 1100 x 1700 elements with up to 5 bits of gray scale. The instrument, one of which is located at The Aerospace Corporation, plots primarily on 35 mm film. (Panatomic X film is required for gray scale images.) The 835 plotter uses a CRT (flying spot technique) to generate the "image". Spot size is of the order of 25 micrometers (0.001 inches) yielding a maximum image size of approximately 28 mm by 43 mm (1.1 inches by 1.7 inches). The basic system has the capability of random address and vector generation. As indicated previously, the Calcomp 835 is primarily directed toward the general computer graphics requirement, but the writer's experience has shown that some reasonably good image (continuous tone) characteristics are possible.

An improved version of the 835 is currently being manufactured by Calcomp as Model 1670 Graphic COM Recorder. The device is, in general, an electronic digital incremental printer. The output can be taken in the following formats:

16 mm (sprocketed or unsprocketed)
35 mm (sprocketed or unsprocketed)
105 mm (full frame or microfiche).

The 35 mm and 16 mm sprocketed cameras are pin registered with sufficient accuracy for strip charting (frame-to-frame butting) or movie generation.

As in the case of the 835, the 1670 recorder is a CRT device with 16,384 addressable positions in both x and y axes. The plotting area or the CRT face is 7.94 cm x 7.94 cm (3.125 inches). General characteristics of the Model 1670 are tabulated in Table I.

Tape Unit

Memory

Read/Write Tape Cartridge Transport

Microfilm Recorder (CRT System)

Minimum line width:	10 micrometers
Linearity:	better than 0.5% (fuil frame)
Accuracy:	$\pm$ 0.5%
Stability:	Approx. 0.1% / 8 hours
Line generation rate:	5 Ms.
Speed:	400,000 increments/sec.
Resolution:	4096 x 4096 spot positions
Addressable Points:	16.384 x 16.384
Intensity Levels:	32

Software (Standard)

1670 Host computer basic software

1670 Graphic controller software

1670 PRINTSIM

Table I

Calcomp Model 1670 System

In addition to the "line" generation capability noted previously, the 1670 alphanumeric capability with the capability of plotting at a rate of 1 character every 25 microseconds.

The Calcomp systems are not recommended for the general digital image display requirement due to the low number of gray scales available. The system may be, however, of interest as a general plotter for any digital computing facility.

Dicomed Corporation

Dicomed Corporation manufactures three different image recorders (hard copy devices) which might be of interest to digital image processing facilities. Many organizations are currently using Dicomed recorders as a part of the basic image processing facilities. Dicomed has primarily made use of the CRT type playback system (sometimes termed a flying spot scanner). Each basic system is discussed in the following paragraphs.

D-40 Digital Image Recorder

The Dicomed Corporation D-40 Digital Image Recorder is essentially a stripped down version of the D-47 recorder discussed in a later paragraph. The instrument is supplied as an OEM device only and includes only the CRT and control electronics. The user must supply any needed optics, cameras, and control panels required. No further discussion will be given at this time. The interested reader is referred to Dicomed for further information. The address and phone number is included in the appendix.

D-46 Black and White Digital Image Recorder

The Dicomed Model D-46 Digital Image Recorder is a black and white system only. The basic specifications were not provided by Dicomed in the initial data transmittal. The device may not be available at this time. As currently understood, the D-46 will permit up to a 2048 x 2048 image display with the ability to format data into quadrants. While the specifications were not sent, the imagery looks very much like 6 or 8 bits of gray scale are available. The interested reader should contact Dicomed directly.

D-47 Digital Color Image Recorder

The D-47 Digital Color Image Recorder is the basic system built by Dicomed for hard copy applications. The D-47 is currently in use

in many facilities concerned with digital image processing and display of data. Characteristics of the basic device are shown in Table II.

Image Size:	Low resolution 512 x 512 pixel (standard CRT)	
	Medium resolution 1024 x 1024 pixels (standard CRT)	
	High resolution 2048 x 2048 pixels (standard CRT)	
Frame Size:	(effective recording area on film)	
	70 mm format (54mm x 54mm)	
	105 mm format (97mm x 97mm)	
	4" x 5" format (86mm x 86mm)	
Resolution:	CRT (standard) 2000 resolvable lines as measured on Ektachrome type 6115 film	
Geometric Accuracy:		
	Matrix orthogonality:	0.5% (0.25% typical)
	Matrix rectangularity:	0.3% max (0.15% typical)
	Line curvature (pincushion):	0.3% max (0.15% typical)
	Spatial repeatability:	0.03% typical, 0.05% max
	Point spacing linearity:	0.25% typical, 0.5% max
Photometric Characteristics:		
	Exposure range:	2.0 D (density units)
	Exposure Uniformity:	0.075 D (density units)
	Input bit size:	8 max
Recording Speed:		
	Spot exposure time 30 microseconds (max) in log mode	
	I/O time 2 microseconds max	
	Adjacent spot positioning time:	8 microseconds max
	Random positioning time:	1.0 millisecond per axis
	Flyback time:	1.0 millisecond
Color Properties:		
	Phosphor:	P48
	Blue filter:	Wratten #47
	Green filter:	Wratten #58B
	Red Filter:	Wratten #25

Table II

Characteristics of the Dicomed Model D-47 Color Digital Image Recorder

An optional CRT is available for use in the D-47 which will permit an increased resolution. The resolution increases from the 2000 lines noted above to 3000 resolvable lines. The result in image generation is to increase the resolution of the displayed image by a factor of 2 in each axis. The CRT spot size is given as 35 micrometers for the standard CRT and 20 micrometers for the high resolution system.

Image generation for the several modes is accomplished by using multiple spots to obtain the desired final spot effective size. In the low resolution mode the system uses 16 spots to create a single pixel, in the medium resolution range four spots are used to create a single pixel, and only a single spot is used to create the pixel in the high resolution mode.

The Dicomed Model D-47 may be used directly with a tape unit as a stand alone device with instructions issued from a control panel, or may be operated by a host computer system with the commands and data through a "standard" Dicomed 8 bit parallel request acknowledge interface.

The control panel will permit the following operations to be initiated from the panel word size selection (6 or 8 bit), random horizontal position, random vertical position, resolution selection (high, medium, low), film advance, normal or image complement, linear or log selection, filter selection (red, green, blue or neutral), and other system requirements such as data start, initialization, end of line, end of image, image waiting, etc.

Basic image display is in a normal raster mode with each pixel sequentially addressed and each word representing the exposure value of the pixel in question. Playback time in the raster mode is relatively rapid. Using a standard CRT a 2048 x 2048 image can be displayed in 4.5 minutes in full color with the log mode activated. The optional high resolution CRT will perform the same task in 16.5 minutes.

Costs of the D-47 recorder are relatively modest. The basic instrument is $43,500. Options recommended would include: high resolution tube ($5,750), high uniformity module ($4,200), character and test pattern generator ($3,750), and film holder accessories (up to $1,200).

D-163 Digital Graphics System

The Dicomed D-163 is an off-line digital graphics support system designed to produce hard copy data for eventual interpretation. The system will provide a full graphics capability as well as support image generation (continuous tone). Dicomed Corporation intended to address the commercial market with the D-163, however, it seems that the capability would be of significant value in the general digital image processing facility.

Elements of the D-163 include the following hardware items:

Dicomed Model D-47 Digital Color Recorder

Digital Equipment Corporation PDF11/05 Computer with 16K words of memory

Dual Density Tape Drive (9 track, 800 bpi NRZI or 1600 bpi phase encoded)

Digital Equipment Corporation DECwriter II terminal

A software system is included which will permit test operations and a series of applications programs.

Characteristics of the display system are the same as the D-47 previously described. Annotation capability of the system will allow a 64 character font with 8 different sizes and up to twelve colors.

System costs were not made available at the time of the survey, it is estimated that system costs will be of the order of $100,000. As indicated earlier, the system would seem to be a valuable aid to the digital image processing facility.

Image Graphics, Inc.

Image Graphics manufactures an electron beam recorder (EBR) which appears interesting as a basic hard copy system. It is understood that the device was originally developed and produced by CBS laboratories who has "turned" over the rights to the device to Image Graphics. The original device was designed and developed for use by NASA (Greenbelt, MD) for use with the Earth Resources Technology Satellite program.

The basic principles involved in the use of an electron beam to write an image on film are not the purpose of this report but some basic theory will aid the user. A very brief review of the principles of operation of the EBR is presented in the following paragraph.

In the simplest sense, the EBR system is nothing more than a direct writing of an electron beam, suitably modulated, on photographic film. The entire system is, however, maintained under high vacuum. An electron beam is emitted from a directly heated thermionic cathode, accelerated (potential of approximately 15kV), focussed and deflected by electromagnetic coils, to an electron sensitive film. The resultant film is then processed in a conventional manner. Image data is processed in a "standard" video channel wherein the data is conditioned prior to the application of the signal to the grid of the emitter system for the modulation of the emitted beam. The video channel is normally used to produce inverted data (positive/negative), gamma correction, as well as other corrections which might be required. The primary problem in the EBR system has been the development of a high voltage coupler which operates at high bandwidth. Typically the bandwidth is of the order of 10 MHz and the voltage level is of the order of -15kV. A beam current servo system is used to maintain constant exposure of the film. Deflection of the beam to scan across the film is accomplished in a variety of ways including: analog deflection of the beam, motion of the film, or combinations of the two methods. Control of the beam is used in many instances to effect corrections to the imagery during the record mode. These corrections generally include: beam aberration geometry, limited exposure corrections, and

some sensor system corrections (distortion, etc.).

Image Graphics, Inc. manufactures twelve different versions of the EBR. Model numbers 2016, 2035, and 2105M have the same spot size (2 to 3 micrometers spots) with the major difference between devices being the size of the film used (ranging from 16 mm to 125 mm). All other models are characterized by spot sizes of 5 micrometers with the exception of Model number 2240U which has a spot size of 7 micrometers. In addition to the variation in film size and spot size, Image Graphics produces a variation based on the type of film transport mechanism ranging from pin registered, sprocketed, unsprocketed, and a multiformat.

The basic EBR system consists of the following components:

- Electron Optics and Controls
- Film Transport and Drive
- Automatic Vacuum System
- Random Access Beam Positioning Unit (32K x 32K)
- Alphanumerics Generator
- Vector Generator
- Digital Input Interface

Optional items (some of which will be necessary for any continuous tone imagery) include:

- Process Control
- Disc Unit
- Tape Units
- Graphics Arts Character Generator
- Raster Scan Generator
- Continuous Tone Recording Capability (required for continuous tone imagery)
- Variety of Optional Film Transport Mechanisms

The option list should be carefully reviewed for the specific application planned if such a device is seriously considered. Functional characteristics of the EBR system are summarized in Table III.

Spot Size:	2.0 to 7.0 micrometers
Resolution:	200 lp/mm 16 mm film
	150 lp/mm 35 mm film
	150 lp/mm 70 mm film
	100 lp/mm 125 mm film
	75 lp/mm 240 mm film
	100 lp/mm 105 mm film
Dynamic Range:	100/1 with D max of 3.0
Film Capacity:	30 to 120 meters
Geometric Distortion:	0.05% standard
Beam Address Matrix:	32K by 32K
Scanning Rates:	250K points/sec in incremental mode
	1000K points/sec in stroke vector mode

Table III

General Characteristics of EBR Systems

On the basis of the brief review of the EBR systems presented herein the electron beam devices appear to be an excellent system for the general digital image processing facility. The high resolution, relatively fast response capability makes the device attractive from the viewpoint of a general graphic system as well as the digital image (or continuous tone) hard copy system. Costs of the system is relatively high in that the basic system ranges from $149,000 to $180,000 and the required/recommended options adding an additional $50,000.

Information International Inc.

Information International Inc. (III) manufactures a range of equipment for the recording and digitization of image data. The devices are of extremely high quality and generally very expensive; four are covered in the survey. Each of the devices is described in the following paragraphs.

The first device is the PFR-3 (Programmable Film Reader/Recorder). This nomenclature indicates that it is both a digitizer and recorder. The digitizer portion is covered in the survey report on microdensitometers. The basic principle of the PFR-3 is that of CRT technology. The CRT system is highly corrected in the computational subsystems and also appears to be of a naturally high quality. The manufacturers of the CRT were not given. The total system consists of the following elements: a programmable light source (scanner CRT), a signal processing and logic unit, a monitor and control display subsystem, and a central processor. The CRT system performs in both the recording and digitizing mode. The characteristics of the CRT system will be covered in the following tables. The signal processing and logic unit are as plot control and discrete positioning. The monitor and control display equipment is the primary man-machine interface with the systems. The subsystem consists of a monitor CRT with the following properties:

Size:	21 inch rectangular tube
Phosphor:	P7 (blue green)
Resolution:	800 TV lines
Spot size:	20 mils
Refresh:	From CP memory
Display positioning:	Electromagnetic
Use:	To scan computer output
Input devices:	Keyboard, light pen, 2 foot pedals

The central processor is of III design and is not a standard unit. It is recommended that the interested reader contact III for further information.

Characteristics of the hard copy device are given in Table IV

CRT Properties:	
Size:	12.5 cm (5 inch) with 7.5 cm by 7.5 cm display
Phosphor:	P-24 (blue green)
Resolution:	6000 TV lines
Addressability:	16,384 by 16,384 with 4.7 micrometer raster
Spot size:	Programmable from 3.6 micrometers 19.6 micrometers
Linearity:	0.05%
Repeatability:	0.025% or 1 part in 4096 long term 1 part in 16,384 short term
Positioning time:	3 microseconds for adjacent points, 35 microseconds for extreme points
Computer corrections to CRT:	
Dynamic correction for distortion, astigmatism, focus, beam size and shape.	
Output Image Properties:	
Gray scale 64 levels	
Density range:	0 to 3.15 (other ranges available as option)
Film Transport:	
70 mm, 35 mm, 16 mm size cameras available	
Frame positioning:	25 micrometers

Table IV

Characteristics of the Information International PFR-3

Costs for the PFR-3 is approximately $465,000 with basic software, computer system and other required peripherals.

The second III system reviewed is the PFR-4. This system is not available at this time as the development is yet to be completed. The basic differences in devices is the increase in resolution from approximately 16,000 by 16,000 points to 64,000 by 64,000 points. In addition to the increased addressability, the PFR-4 offers an increase in speed from 3 microseconds to 0.5 microseconds for adjacent points. Principles of operation are, however, the same as that of the PFR-3. It is recommended

that future efforts on the PFR-4 be carefully monitored as it may well be the best system available for black and white recording. One additional improvement is the increase of the gray scale capability to 9 bits (512 levels of gray), with a writing speed of 400,000 points per second at the 9 bit data.

Costs of the PFR-4 are not known at this time.

The next III system reviewed is the COMp 80 Publication System which is primarily directed toward the publication market for text management and printing on film. The device is very similar to the Model FR-80 which will be discussed in the next system description. The COMp 80 consists of the following units or subsystems:

Control Input (ASR 33 teletypewriter, paper tape, and punch)

Data Input (Magnetic Tape Unit, 800 bpi, 9 track, 45 ips)

Central Processing Unit (III I-15 computer)

Recording Unit (CRT, character stroke generator, camera mount and camera).

Options include a wide variety of camera systems ranging from 16 mm to 215.9 mm x 298.5 mm (8.5 in x 11 in) with a variety of sprocketed, unsprocketed, and pin registrations. The one particular option required for general use as an image processing tool is the full graphics package which will permit up to 9 bits of gray scale. Color recording is also available.

The FR-80 represents the top of the line as far as image processing equipment is concerned. Like the other III systems, the FR-80 is based on flying spot recording technology using a CRT system as the optical source. The basic elements of the FR-80 are:

Central Processing Unit: (programmable, 8192 18 bit core memory control logic, data buffer, and stored program control)

Control Input: (ASR-33 teletypewriter, paper tape punch and reader)

Data Input (Magnetic tape unit and control)

Recording Unit: (High resolution CRT, camera and camera mount, camera, vector generator, character generator, and CRT monitor).

Several options will be required for full utility in the general image processing facility. The required options include: gray level recording (allows up to 256 levels of gray), color recording (which may require a special CRT), and other associated peripherals (such as extended core memory).

Specific characteristics of the FR-80 are summarized in Table V, based on the minimum required options.

Image Generated Characteristics:

Image addressed points:	Up to 16,384 points x 16,384 points
Image resolution:	Up to 4096 x 4096 pixels
Gray scale:	Up to 9 bits per color plane
Film sizes:	16 mm to 215.9 mm x 298.5 mm
Spot size and shape:	8 programmed levels and spot shapes available
Character generator:	128 to 240 characters stored
Write Speed:	Binary images approximately 1 second
	Gray scale images (4096 x 4096 at 6 bits) approximately 30 seconds (some question as to the actual time)

Table V

Information International

FR-80 Graphic Recorder Characteristics

Costs of the FR-80 are not quite as high as the PFR-3 but are still significant. Basic system costs with the required options will run between $280,000 and $300,000 for a moderate system. The capability for expansion and the quality are not matched in many other systems available on the market.

Marco Scientific

Marco Scientific is the responsible organization for the Joyce Loebl systems. Only one hard copy device was provided in response to the survey inquiry. The system is called Joyce Loebl Filmwrite 2. Principles of operation and specifications are described in the following paragraphs.

The system consists of a rotating drum around which the film to be written is mounted. The digital image data is used to modulate a light source (type unknown) for imaging onto the film. The drum rotates to expose a line of data and the carriage is indexed to a new position for the next line. The system is loaded with roll type film allowing space for up to 300 images. One of the interesting features of the system is the "built in" automatic film processor. The instrument delivers a finished print to the user at a collection bin built into the instrument. No dark room facilities are required. The type and manufacturer of the film processor is unknown. Types of film required were not specified.

Specifications provided are summarized in the following table (Table VI).

Operation:	Fully automatic
Picture size:	254 x 267 mm
Picture inversion:	Positive/Negative
Resolution:	8 line pairs/ mm
Input data:	8 bit binary (the image matrix size was not given)
Total process time:	16 minutes (to finished print)
Picture source:	Computer (interfaces unknown), radio link (bandwidth, and other link parameters unknown), telephone link (parameters are unknown)

Table VI

Characteristics of Joyce Loebl Filmwriter 2

On the surface, the Filmwrite 2 appears to be an interesting instrument due largely to the capability of built in photo-processing. Further review is recommended.

Mead Technology Laboratories

One of the most unusual hard copy systems surveyed is the Data Digital Graphics Generator (DDGG) manufactured by Mead Technology Laboratories (MTL). The system utilizes an ink-on-paper technique wherein a four color (cyan, magenta, yellow, and black)ink supply is "sprayed" onto the copy medium. The copy medium may be paper, transparency or a similar material. One of the most obvious advantages is the immediate availability of the image (i.e., no photographic laboratory is required). The basic system also produces a large hard copy format (up to 102 cm by 152 cm (40 inches by 60 inches).

The system utilizes a patented system of electrostatically credit dot matrices which is built into the basic system. The images are generated by up to 40,000 ink drops per second. Characteristics of a basic system are shown in Table VII.

Operation:	Ink on paper
Format:	100 cm x 150 cm (40 in x 60 in)
Dot size:	0.127 mm
Pixel size:	4 x 4 dot matrix (0.508 mm x 0.508 mm) (approximately 28 pixels/cm)
Number of gray levels:	Up to 60
Write speed:	90 minutes for 100 cm x 150 cm image (must use full size)

Table VII
Mead Technology Laboratories
Digital Graphics Generator
(Bikini Printer)

Costs for the DDGG are of the order of $250,000.

In addition to the DDGG system previously described, MTL also is building a laser printer which is designed to directly write onto paper in a large format. The system is primarily concerned with the printing of alphanumerics but is claimed to have the capability of some gray scale using a 4 x 4 printing (half tone) matrix for each pixel. In operation, the system uses a laser beam which is swept across the film sheet. The film sheet is held to a concave platen by a vacuum hold down technique. A mirror system is driven to cause the laser beam to travel across the film sheet. The beam is modulated in an off-on fashion with the input data. The curved platen reduces the need for correction optics to produce the usual flat field. In essence, the system looks like the "Bikini" printer previously discussed with the exception of the use of film and the laser write mode. Characteristics of the system, called the Digital Laser Printer are shown in Table VIII.

Format size:	364 mm x 610 mm (14.3 in x 24 in)
Dot size:	0.063 mm
Pixel size:	4 x 4 matrix (0.0445 mm centers)
Number of gray levels:	60 claimed
Printing time:	2.5 minutes for full frame

Table VIII

Mead Technology Laboratories
Digital Laser Printer

A brief description of the Digital Laser Printer is given in the Journal of the American Society of Photogrammetry, Photogrammetric Engineering and Remote Sensing, Vol XLII no. 5, 1976 (page 703).

Costs of the Digital Laser Printer are of the order of $100,000 to $200,000.

No immediate application for either device is seen for either MTL system.

Optronics International, Inc.

Optronics International, Inc., manufactures several series of hard copy devices including both flatbed and rotating drum types. Both color and black and white systems are manufactured.

The first system to be described is the Photowrite System P-1500. The P-1500 is a high speed, rotating drum film writer. The optical source is a light emitting diode which is modulated with the desired intensity. The system is capable of moderately high recording rates up to 60,000 points per second. The film is exposed along the circumference of the rotating drum. After each rotation, the drum is stepped along the axial direction in preparation for the next line of data. A summary of pertinent characteristics is given in Table IX.

The system costs vary between $27,682 and $46,134 depending upon the options selected. The second system by Optronics surveyed is also a rotating drum scanner but does use a light emitting diode (LED) array. The standard instrument, designated as system P-1550 Photoplot Mark I, is designed to handle binary images, however, one option does allow for 64 levels of gray. The system is briefly described in the next paragraph.

Film is loaded into the rotating drum in a dark room environment. The loaded drum is remounted into the instrument. A multiple head LED array is driven by 8 single bit digital input signals such that points 50 micrometers square are formed around the circumference of the film (50 micrometers for each diode). The data then covers 400 micrometers for the instantaneous diode array. After the exposure the drum steps 400 micrometers for the next set of data. The system is limited to a 50 micrometer resolution and 50 micrometer raster.

The option package offered circumvents some of the problems noted above. The options allow a 25 micrometer aperture and raster as well as 64 levels of gray over the range of 0 to 2.5D (density units). The basic characteristics of both the standard and options are given in Table X.

Costs for the P-1550 with an assortment of options, including 25 micrometers aperture and raster and gray scale, will be of the order of $92,000.

Output Specification:

Maximum format 20 cm x 25 cm

Maximum photographic density = 2.5 (specular density units)

Scanner Specifications:

Aperture: square (12.5 micrometers, 25 micrometers 50 micrometers, 100 micrometers; and 200 micrometers)

Raster: (orthogonal)

Models 10, 30C:	50, 100, and 200 micrometers
Models 20, 30D:	25, 50, and 100 micrometers
Models 40, 30E:	12.5, 25, and 30 micrometers

Density:

Range:	0 - 2.5 D
Resolution:	64 gray levels

Positional Accuracy:

x axes - 2 micrometers RMS

y axes - 2 micrometers RMS

Data Rates:

Up to 60 KHz from computer, 36KHz from from magnetic tape (8 bit)

Tape Unit:

7 or 9 track (to 800 bpi) NRZI

Tape speed	45 IPS
Data rate	36 KHz

Table IX

Optronics Model D-1500 Photowrite

Standard:	Black and White (binary) generation
	Drift-free operation
	50 micrometer aperture and raster
	Aperture - square only
	Multiple head plot (8 LED's)
	43 cm x 56 cm image size
	Record rates to 200,000 points/sec
	Positional accuracy to $\pm$ 2 micrometers
	Density repeatability to $\pm$ 10%
	Data rate: 200 KHz max
	Auto zero
	Drum speed: 3 rps
	Plot time (43 cm x 56 cm) 8 min
Options:	Automatic half-tone screen generation
	Fixed 25 micrometer aperture and raster
	Gamma correction
	Color separation products
	64 levels of gray
	Format to 91 cm square
	Density range 0 to 2.5 D
	Record rates to 400,000 points/sec

Table X

System P-1550 Photoplot Mark I

(Optronics International, Inc.)

The third Optronics system reviewed is the P-1700 Photomation Mark II. The system is a "total" device in that both image scan (sample and quantize) and image playback are performed in the same instrument. Only the hard copy playback will be discussed herein. The scan portion is described in the survey report on microdensitometers by M. M. Irvin.

The write mode for the P-1700 is essentially the same as for the Model P-1500. Table IX summaries those basic properties. The standard output image format is 12.5 cm x 17.5 cm with options of 25 cm x 25 cm, 35 cm x 43 cm, 43 cm x 56 cm, and larger depending upon the system.

Costs for the P-1700 range from $47,600 to $83,300 depending upon options selected.

A rotating drum system capable of color image generation is available from Optronics as the C-4000 series. Only two of the C 4000 series, the C 4300 Colorwrite and C 4500 Colormation systems, are suitable for color image generation. The two instruments have essentially the same playback characteristics, but the C 4500 Colormation system has a color scan capability. Only the color write capability will be addressed herein.

Digital image data from the computer is converted to analog signal for plotting on film. The unexposed film is mounted on the rotating drum which is mounted in a light tight cassette. The film is exposed by pulse modulation of a light source from a "white" light glow crater tube. The "modulated" light beam is focussed onto the film plane through a precision lens and aperture system. The color write is accomplished through three sequential exposures through computer control of red, green, and blue filters. The film is exposed at every raster point along the circumference of the rotating drum. After each rotation, the drum is axially stepped for the next line. Modulation of the glow crater tube is of the order of 100/1 which produces a dynamic film density of approximately 2 density units.

Table XI presents a brief summary of the characteristics of the C 4000 Colorwrite system.

Film Format:	20 x 25 cm, 25 x 25 cm, 35 x 43 cm
Apertures	25, 50, 100, and 200 micrometers. Special apertures on request.
Illumination Spot Sizes:	25, 50, 100, or 50, 100, 200 micrometers
Rasters:	Same as aperture systems
Pixel Scale Factors:	1:1, 1:2, 1:4
Positional Accuracy:	2 micrometers RMS
Density:	
Range	0 - 2 density units
Resolution:	32 true colors/primary color
	64 levels of gray in black and white
Data Rate:	28 Kbps
Write Time:	25 cm x 25 cm @ 100 micrometer raster in 10 minutes

Table XI

Optronics C 4000 Colorwrite Characteristics

Costs for the color capability in the C 4300 Colorwrite range from $54,200 to $60,700 depending upon options selected. The C-4500 Colormation (which provides both color scan and write capability) costs range from $76,200 to $108,400 depending on options for an on-line system. The stand alone devices would, of course, require a computer and peripherals which will not be discussed here.

The last Optronics system reviewed in this survey is the High Resolution Flat Bed Scanning and Writing System (Model S-3000 Specscan). The S-3000 system provides both scan and write capabilities.

In principle, the Specscan is nothing more than a massive stage on which the film to be scanned or written is mounted on a flatbed. The stage is caused to move in some prescribed pattern under computer control. A readout system continually monitors the stage in both x and y coordinates. In the write mode, a modulated white light source is used to expose the film sample. The film is mounted in interchangeable cassettes for ease in handling.

A summary of the S-3000 system characteristics is shown in Table IV. The model used was IX. The model used was S-3400 Photomation Mark IV.

Base:	Precision Granite
Positioning:	Independent x - y stages on self cleaning air bearings
Write Area:	25 cm x 25 cm
Rotary Control:	360^{o}
Projection Screen:	Variable magnification from 25 to 400 X
Stage Encoder:	Glass, $\pm$ 1 micron accuracy
Apertures:	8 provided (customer to specify)
Color Fillers:	Manual switch (motorized as option)
Gray Scale:	Up to 64 levels

Table XII

Optronics S-3400 Photomation Mark IV

Costs for the basic instrument is approximately $118,000. A series of options are available which should be carefully reviewed.

Perkin-Elmer

Perkin-Elmer manufactures a precision microdensitometer with a hard copy capability through their Boller & Chivens Division Division. The instrument is designated as the Model 1010. Details of the hard copy operation for both black and white and color are given in the following paragraphs.

The basic properties such as scan properties, mechanical precision, and optical properties are basically controlled by the microdensitometer system. The photographic playback is an option which may be acquired with the microdensitometer. There are two versions of the Model 1010 noted as the A and G version. The A is a steel stage while the G is a granite stage. The basic technique is the same in either system and only the A model will be described herein. The basic system is a two axis flatbed device in which each axis is driven by a precision DC servo motor. Feedback tachometers are used to insure stability and uniformity of motion. Stage position is provided by meter indicators on the control system rack. The position readout is updated each micrometer of stage travel. The entire system runs under the control of a mini-computer either the Digital Equipment Corporation PDP 11/05 or the PDP 8.

The playback option includes both a black and white system using an LED (Light Emitting Diode) or color using a three gun CRT to produce the color through a set of three filters. Basic characteristics of the system are shown in Table XIII.

Specific characteristics of the color playback system are of particular interest in that both a CRT system and stage motion are used in achieving the image. Many options are available especially in the area of selection of the color characteristics of the system. In essence the user may custom design the spectral filter required for matching any film type.

Stage Properties:

X and Y axis travel	25 cm
X and Y axis repeatability	1 micrometer
Straightness of travel	5 micrometers
Axes orthogonality	5 seconds of arc
Flatness of platen travel	5 micrometers
Stage rotation	360 degrees

Linear Optical Encoder:

Accuracy error not to exceed 1 micrometer per mm of travel, or to exceed 3 micrometers total stage travel.

Scanning Rate: maximum of 60,000 micrometers/second

Black and White Playback:

Source:	LED (red band)
Spot Size:	2 to 500 micrometers
Spot Shape:	Square, circular, rectangular

Color Playback:

Source:	Three gun CRT with spectral filters
Type:	Sequential Red, Green, Blue

Table XIII

Characteristics of the Perkin-Elmer 1010A System

Resolution:	5 to 50 line pairs/mm (10 to 100 pixels/mm)
Exposure:	10 microseconds nominal, adjustable to 100 microsec
Data handling time:	32 microseconds
Maximum pixel frequency:	23.8 KHz at 10 microsecond exposure 7.6 KHz at 100 microsecond exposure
Maximum write rates:	33 minutes per square inch at 100 pixels/mm 2 minutes per square inch at 10 pixels/mm
Pixel smear:	6% with 10 micron pixel at 60 mm/second 20% with 10 micron pixel at 200 mm/second
Dynamic range:	Up to 100/1 by amplitude modulation, each gun is separately adjustable over a range of 1000/1
Gray levels:	Up to 1024
Spectral output:	Selectable by changing bankpass filters, Total range limited to 0.365 micrometers to 0.68 micrometers by CRT phosphor.

Table XIV

Characteristics of The Perkin-Elmer Color Playback Option

Costs for the playback options for the Model 1010A microdensitometer range from approximately $5,000 for the black and white system to approximately $18,500 for the color option. The costs are in addition to the basic costs of the microdensitometer system which can run close to $100,000 depending upon options.

CBS Laboratories

Laser recording devices have been manufactured by many different organizations but few have been developed to the point of "full" production. Many of these organizations were contacted with respect to the status of their laser recording systems with the result that the companies are no longer interested in future development. This portion of the survey was a significant disappointment. It was felt that at least one laser device should be described to complete the survey. The only device to be discussed is the CBS LIPS (Laser Image Processing System). It should be noted that CBS is no longer manufacturing the LIPS. The instrument is now the property of EPSCO who have also decided not to continue with manufacturing.

Details of the LIPS are very sparse due, probably, to the confusion as to the manufacturer. Table XV presents the general characteristics of the basic record mode. The LIPS is also used in the scan and digitize mode and the reader is referred to the Survey report on Digital Scanning Systems by M. M. Irvin. The basic device is a rotating drum type with the film mounted around the periphery of the drum. The laser beam is deflected on the film. Details of the modulation technique are unknown as are the extinction properties. Several LIPS scanners/recorders have been procurred by the government. It is recommended that the interested reader contact one or more of the users of the system. One user of particular interest is the Range Measurement Laboratory (RML) at Patrick Air Force Base, Florida.

One evaluation which was performed on the LIPS device is reported in the following reference:

> H. C. Andrews, "Digital Fourier Transforms as Means for Scanner Evaluation", Applied Optics, Vol. 13 No. 1, January 1974.

The referenced article points out many of the difficulties of the laser devices alluded to in an earlier section of this report. One of the major problems noted is the line jitter or line start error. The artifact is most

bothersome to the user. In the particular system the image data is deflected onto the film by means of an eight sided mirror. Bearing wear accounts, most likely, for the effect.

Based on capabilities of currently available systems, no laser recorders would be recommended. The future should bring some significant improvements in the state-of-the-art.

Film Chip Size:	70 mm x 100 mm
Electronic Aperture:	512, 1024, 2048, 4096 pixels
Output Levels:	8 bits (256 levels)
Maximum Density:	2.56 Density Units
Spot Characteristics:	
size:	10, 20, 40 micrometers
shape:	Gaussian, elliptical capability
Resolution:	37.5, 19.8, 9.4 line pairs/mm
Magnification:	8X, 16X, 32X
Framelet Size:	10.2, 20.5, 41.0 mm
Write Time:	9 minutes (1024 x 1024 pixels)

Table XV

CBS LIPS Recorder Characteristics

CONCLUSIONS AND RECOMMENDATIONS

Results of the survey on hard copy systems was highly disappointing in that little was found that is new. The basic system types seen included flying spot scanning, a few laser devices (mostly "one of a kind"), rotating drum with incoherent sources, and several flatbed systems based on microdensitometer techniques. No one instrument seemed to fit general requirements in terms of accuracy in both the spatial and photometric sense or general utility. The color hard copy systems are less common than one might expect with current interest in wide dynamic range display. Perhaps one of the most troublesome problems is the speed of response associated with the reviewed hard copy systems. Most of the systems reviewed are very slow, too slow in fact, to be of any real value in a "near" production environment. The few systems seen which are suitable for production activities are very expensive due largely to the inclusion of additional functions (such as graphics and alphanumerics).

As far as a ranking of instruments for a hard copy system, none can be made without a detailed review of the applications intended. It does seem that the highest quality instruments are those from Information International, Inc. however, the specific systems are among the most expensive. At the next level of quality, the Dicomed D-47 seems to be of sufficient quality to meet most reasonable requirements. The primary problem with the Dicomed system is the small image size capability (up to 4096 x 4096). The EBR should also be satisfactory for most applications, however, the instrument is quite complex with the requirement for vacuum and special controls.

APPENDIX

ORGANIZATIONS SURVEYED
FOR
HARD COPY SYSTEMS CAPABILITY

The following is a list of organizations and associated addresses which were contacted for data regarding hard copy capability.

1. California Computer Products, Inc.
   2411 W. La Palma
   Anaheim, CA 92801
   Telephone: (714) 821-2011

2. CBS Laboratories
   227 High Ridge Rd.
   Stanford, CT 06901
   Telephone: (203) 327-2000

3. Dicomed Corporation
   7600 Parklawn Ave.
   Minneapolis, MN 55435
   Telephone: (612) 888-1900

4. EPSCO
   411 Providence Hwy.
   Westwood, MA
   Telephone: (617) 329-1500

5. Image Graphics, Inc.
   1525 Kings Highway
   Fairfield, CT 06430
   Telephone: (203) 336-1778

6. Information International
   5933 Slauson Ave.
   Culver City, CA 90230
   Telephone: (213) 390-8611

7. Marco Scientific
   P.O. Box 2699
   Santa Clara, CA 95051
   Telephone: (408) 739-9418

8. Mead Technology Laboratory
   Research Park
   Dayton, OH 45432
   Telephone: (513) 767-7004

9. Optronics International, Inc.
   7 Stuart Rd.
   Chelmsford, MA 01824
   Telephone: (617) 256-4511

10: Perkin-Elmer Corporation
   Boller & Chivens Division
   916 Meridian Ave.
   South Pasadena, CA 91030
   Telephone: (213) 682-3391